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The study of the performance improvement possibilities by using the principle of zonal cooling for the automotive engine

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Abstract. The transformation of chemical energy of the fuel into mechanical energy, through the heat emitted during its burning is accompanied by losses. These losses are manifested, in general, as the amount of heat. They are mainly found in combustion gases and in the cooling fluid.

1. Introduction

The improvement of the performance of any internal combustion engine is based on the thermal optimization and gas dynamics processes.

The experience shows that the optimal temperature of the coolant flowing through the outside of the cylinder should be around 90 °C. Close to this temperature, the cylinder and other components wear is minimal.

Under these conditions, the required temperature distribution along the cylinder's sleeve is shown in figure 1.

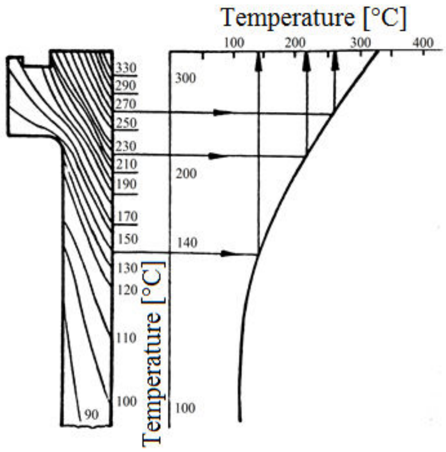


Figure 1. Temperature variation in cylinder in the exhaust valve area.

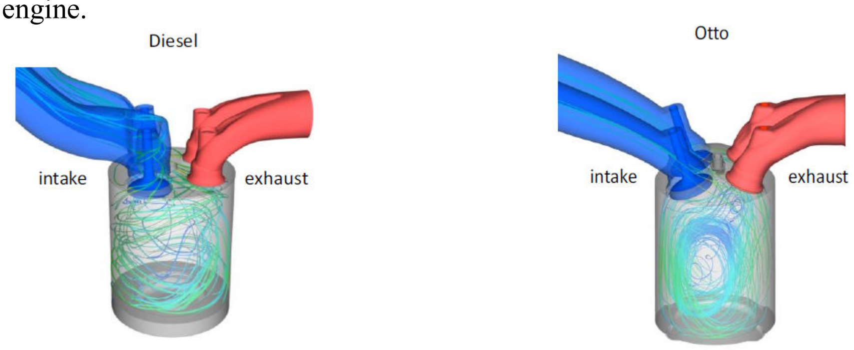
Cooling of the cylinder head requires special attention due to the problems caused by the unevenness of the temperatures. Of all the engine parts, the cylinder head receives the highest quantity of heat. This amount of heat comes from the cylinders and from the exhaust channels. From the cylinders the heat it is transmitted by radiation and by direct contact with the engine fluid and from the exhaust channels the heat it is transmitted due to direct contact with the combustion gases. As is known, the quality of the fresh charge, as well as the evolution of temperature, influences the heat transfer.

2. Theoretical basis

The motion of the fresh charge and the evolution of his temperature have a large effect on heat transfer. On the other hand, the wall temperature has only marginally effect on the flow pattern and on the chemistry of the main flow. On the other hand, the thermal interaction between the fresh charge and the engine walls can be considered to be reciprocal [4].

Figure 2 gives a graphical overview of the in-cylinder charge motion.

In other words, it is a multidimensional, time-dependent internal flow induced by a geometry change. Consequently the heat transfer coefficient varies along the cylinder's surface. The charge entering the cylinder is in general at a lower temperature than the engine walls. Consequently, the fresh charge provides a small cooling effect to the intake ports and components. This phenomenon does not directly contribute to engine heat loss and could be ignored in the study of the overall energy balance of the engine.



(a) (b)

Figure 2. Example of in-cylinder charge motion at end of intake stroke:
(a) – MAC; (b) – MAS. [4]

On the other hand, the heating of the fresh charge lowers its density. The consequence is a reduced volumetric efficiency. Furthermore, knowledge of the heat flux on the intake ports is necessary to solve the entire temperature distribution of the cylinder head, a component which is difficult to design and prone to failure [4].

Analysing these conditions, to achieve a lower disposition to detonation and in particular a good filling coefficient, leading to the high performance, the temperature of the engine cylinder head it is necessary to be lower than that of the cylinder. The lower predisposition to detonation can also be expressed by reducing the octane number as the temperature of the coolant decreases as shown in figure 3.

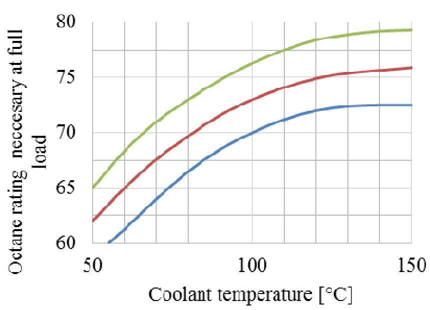


Figure 3. Octane rating according with liquid coolant.

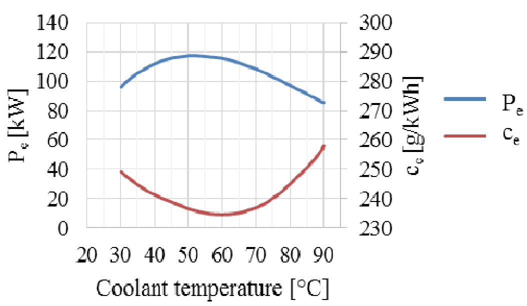


Figure 4. Optimal coolant temperature [2].

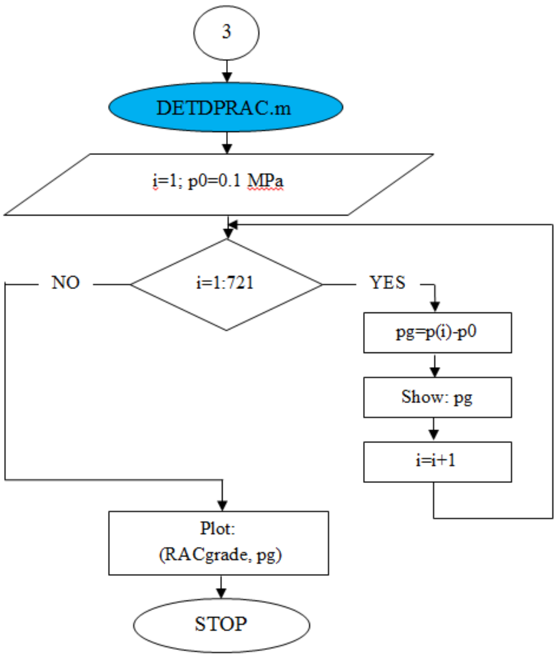
Tests conducted in our country [2] show that the optimal temperature of the coolant in the cylinder head of the engine, in terms of performance and power consumption, is about 40 ÷ 56 ° C, fact highlighted in figure 4. In this context, the more intense cooling of the cylinder head relative to other engine organs appears to be a more rational solution, especially since the lower temperatures of the other parts of the engine would lead to their intense wear due to friction and corrosion. Reiterating the idea, reducing the temperature of the cylinder head increases the filling coefficient, reduces the intensity of detonation and increases valve durability. On the other hand, the cylinder achieves convenient effects by increasing the temperature. Such a principle, called differentiated cooling, is known and has already been used, but is not spread in the production of automotive engines.

For each type of engine, depending on the thermal stresses, optimal operating temperatures can be set in the two independent cooling circuits using this principle.

As has been shown above, the cylinder head is subjected to the strongest heat flow from all the engine components. In addition, the thermo-mechanical stresses of the cylindrical head are also amplified by the uneven distribution of temperatures in different areas. In the present paper the implementation of differential cooling is studied and grounded. This differential cooling theory will be extended by organizing a preferential circulation of fluids involved in the cooling process. In this way, it is expected that it will be possible to control and adjust the temperature of the cooling agent in the areas of interest of the cylinder head, corresponding to the various operating conditions characteristic of the engine during starting, heating, partial or nominal loads. It is appreciated that in this way the performance of the engine will be improved.

3. Opportunities to improve the performance of spark ignition engines by differential cooling

For this purpose, it is intended to optimize the zonal thermal regime and to improve the engine filling coefficient, thus allowing for the use of higher compression volumetric ratios that can contribute to increasing the engine performance. Thus, the reduction in the degree of heating of the fresh load as it travels along the intake path, on the one hand, as well as the possible additional cooling of the cargo and walls of the combustion chamber by the vaporization of the fuel, especially when using the direct injection, on the other hand, lead to an increase in the self-ignition delay and ultimately to a reduction in the detonation trend. Therefore, it is possible to increase the compression volumetric ratio, ε.




```
%Pressure plot according with °RAC

for i=1:length(p) pg(i)=p(i)-p0; end% Mpa

figure
%subplot(2,1,2),...
hold on,...
title('GAS PRESSURE')
plot(RACgrade,p);
xlabel('alfa [RAC]'),...
ylabel('p [Mpa]'),...
grid;
```

(a) (b)

Figure 5. (a) Logical diagram for plotting graph - pressure variation according to °RAC.
(b) Section from MatLab program for plotting graph - pressure variation according to °RAC.

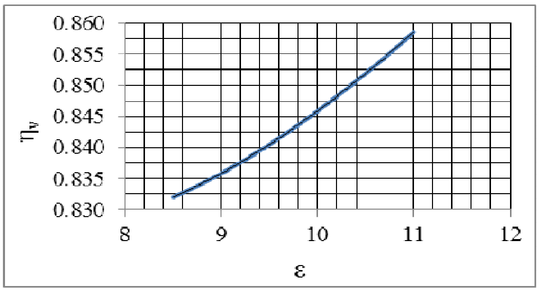
Starting from the principle of differential cooling, the use of the engine's zonal thermal regime ensures conditions for operation with a leaner mixture than with normal cooling, which obviously helps to improve the economy. In order to estimate the performance of the engine in various situations provided by the implementation of the zonal thermal regime, a logical diagram and a calculation program were developed. The program was developed in the MatLab work environment, which has evolved over the last few years, being recognized as a powerful numerical investigation tool used to support high-level research, development and analysis.

Figure 5 (a), (b) shows the logic diagram and calculation subroutine for determining and plotting the pressure variation according to the angle of the crankshaft.

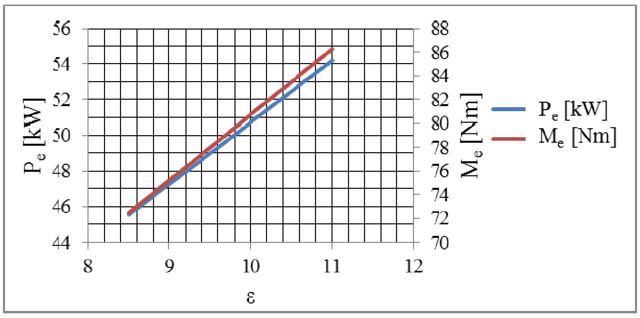
4. Theoretical results

Based on the calculation program performed for performance estimation, were obtained variations of the filling coefficient, η_v, depending on the change of the compression ratio, ε.

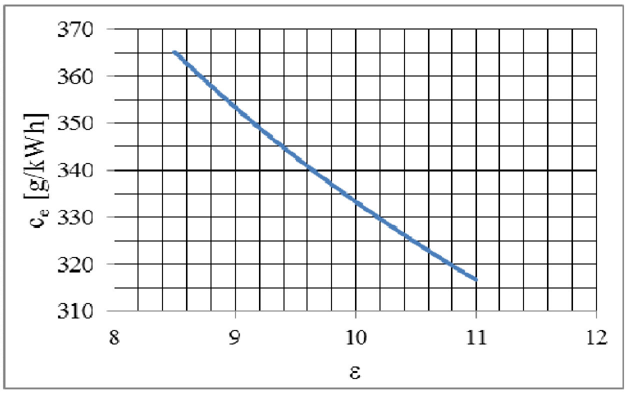
We also obtained the variation of the effective power P_e, the effective torque M_e, and the fuel consumption c_e. All this is shown in the figure 6. (a), (b), (c).



(a)



(b)

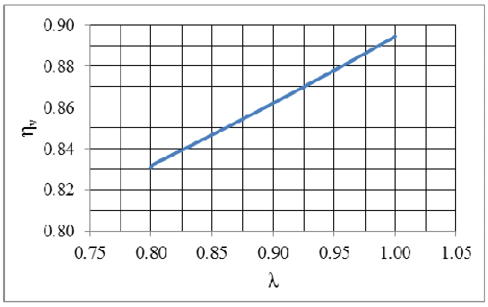


(c)

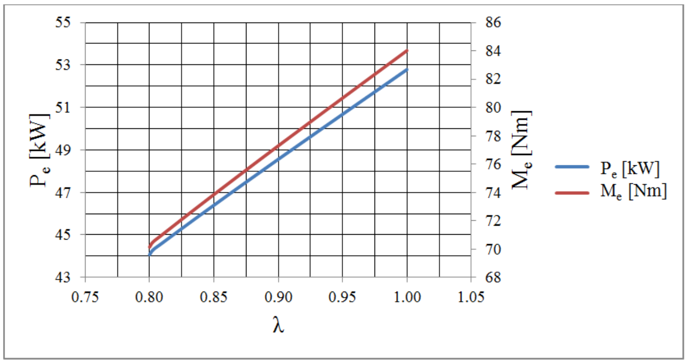
Figure 6. Variation of effective engine parameters according to filling coefficient and compression ratio: (a) the filling coefficient variation depending on the compression ratio modification, (b) the variation of the effective power P_e, the effective torque M_e depending on the compression ratio modification, (c) fuel consumption variation depending on the compression ratio modification.

By interpreting the above graphs, we can see that increasing the compression ratio value provided by the zonal cooling process leads to a substantial increase in effective power and effective torque while reducing specific fuel consumption. As has been shown, this differential cooling regime provides conditions for operating with a leaner mixture than normal cooling, which obviously contributes to improving the economy.

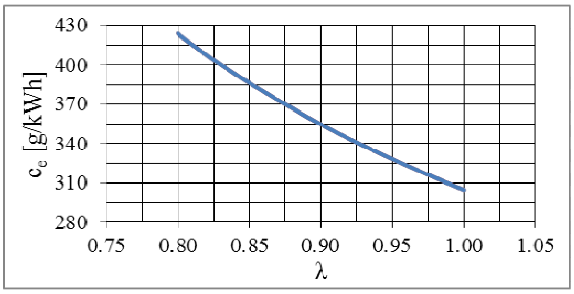
The variation of energy performance and actual fuel consumption by increasing the value of air-fuel equivalence coefficient λ is shown in figure 7. (a), (b), (c). In this case, there is a strong favorable influence of the increase of the filling coefficient η_v.



(a)

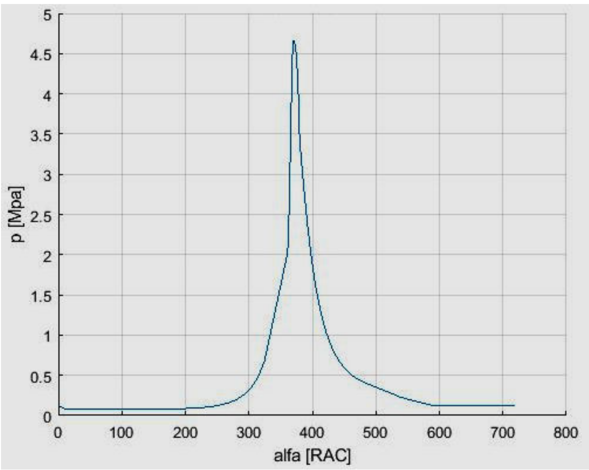


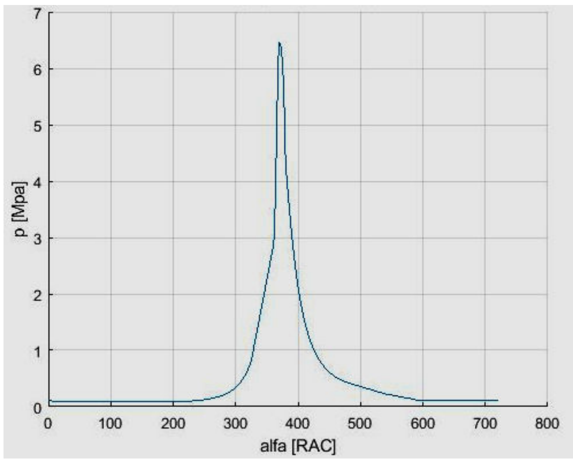
(b)



(c)

Figure 7. Variation of effective engine parameters according to filling coefficient and air - fuel equivalence coefficient: (a) Variation of filling coefficient according to air - fuel equivalence coefficient, (b) the variation of the effective power P_e, the effective torque M_e depending on the air - fuel equivalence coefficient modification, (c) fuel consumption variation depending on the air - fuel equivalence coefficient modification.





(a) (b)

Figure 8. Variation of cylinder pressure due to increased compression ratio at the same time as reduction of heating of the fuel mixture with fresh air.
(a) ΔT = 40 [°C] ε = 8.5, (b) ΔT = 15 [°C] ε = 11

The calculation algorithm developed was obtained the pressure variation in the cylinder due to compression ratio in the same time with the reduction of the heating of fresh air fuel mixture. These values are plotted in figure 8.

Based on this study, we managed to obtain, at the same time, the pressure variation in the cylinder depending on the compression ratio (figure 9) and the degree of heating of the fuel mixture with fresh air (figure 10).

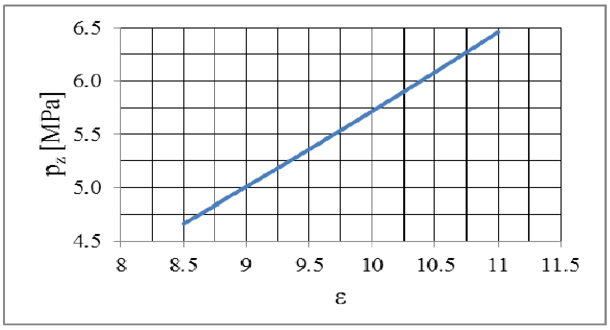


Figure 9. Pressure variation from the cylinder according to the compression ratio

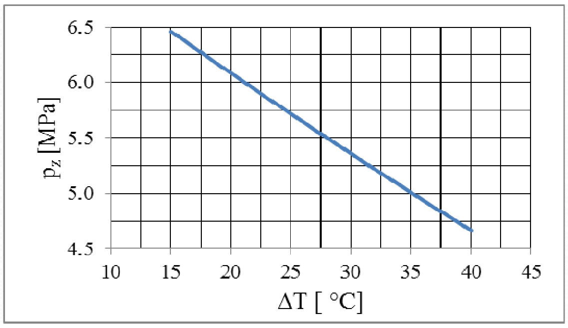


Figure 10. Pressure variation from the cylinder according to the reduction of the heating of fresh air fuel mixture

5. Conclusions

By interpreting the above graphs, we can see that increasing the compression ratio value provided by the zonal cooling process leads to a substantial increase in effective power and effective torque while reducing specific fuel consumption.

It can be concluded that improvements in engine performance, prefigured by the authors computational algorithm, are the obvious premises for studying and developing the engine cooling zone.

Simultaneously with this improvement in engine power and torque, on average about 18.65%, there is also a reduction in brake specific fuel consumption along with improved filling and increased compression volumetric ratios.

The combined effect of these two factors leads to an estimated decrease in brake fuel consumption by approximately 13.3%, which represents a significant reduction in the value of this parameter in the case of the propulsion engine.

6. References

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